# *Automobiles in a Sustainable Energy World*

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# Energy – A World in Transition

**20th Century Assumptions:**

- Industrial revolution was based on availability of unlimited natural resources and a limitless environment.
- Global business model was based on availability of abundant low-cost energy. Costs were not fully accounted for.
- Only the powerful nations consumed high per capita energy.
- Problems were assumed to be single dimensional and linear, and complex interdependencies were ignored.
- Climate change was not considered real, there was no evidence for it.

**21st Century Realities:**

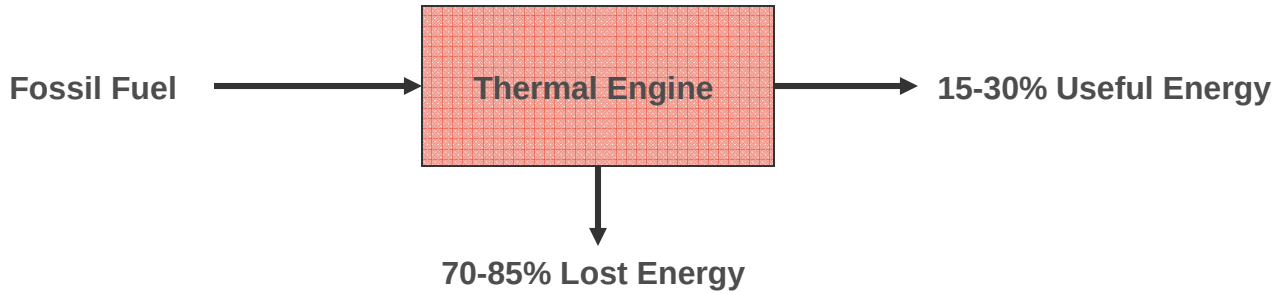
- Globalization and the IT revolution have brought billions into the mainstream, raising aspirations, and creating competition for dwindling natural resources
- Natural resources and the environment are finite and reaching a limit. Every solution has unintended consequences. Climate change is real & accelerating.
- Reducing energy consumption will be unacceptable for emerging economies, especially when per capita energy consumption in India is 4 MWh/year and in the US is 82 MWh/year.
- Energy is the first challenge to be addressed. With fossil fuels, it is a zero sum game. With abundant sustainable energy, all other issues can be solved.

# Future Energy Infrastructure – What Will It Look Like?

- Two energy delivery infrastructures exist today
  - Fossil fuel extraction, refining, delivery and utilization (mobile)
  - Coal, gas, hydro and nuclear – conversion to electricity (stationary)
- A future energy infrastructure will likely build on one of these. Both industry groups will try to maintain their paradigms at all costs.
- What will the cars of the future run on – liquid fuel or electricity? The ideal answer for the automotive industry is liquid fuel because then the automotive complex does not have to change.

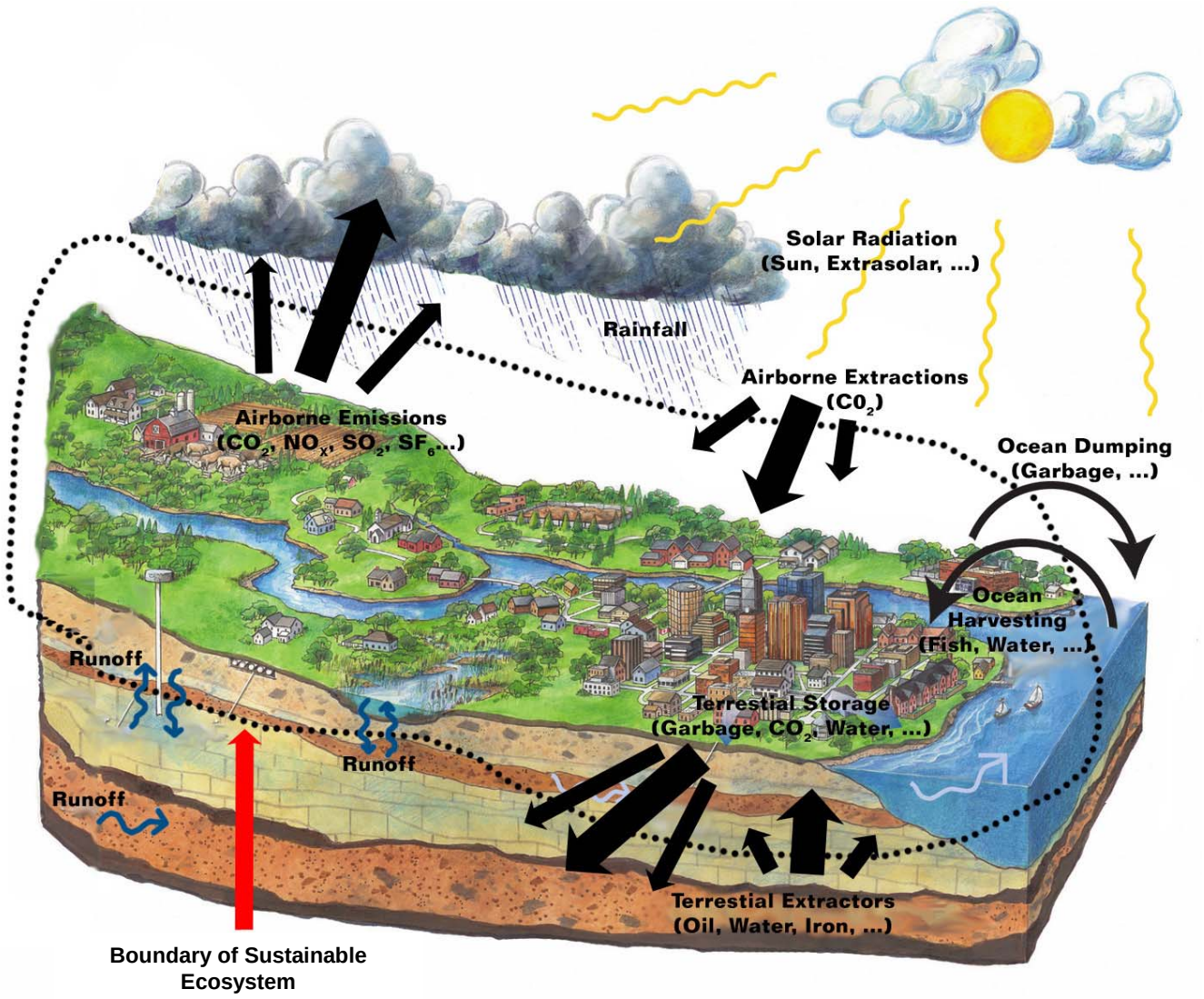
- Will we run out of oil? Has oil peaked? NO and NO! Oil still has legs, but the price will keep increasing as China and India increase consumption.
- Biofuels are becoming cost competitive and provide an alternative to petroleum.
- Cane and corn based ethanol, cellulosic ethanol, algae derived biofuels – Exxon just paid $600M for a piece of Craig Venter's company.
- With biofuels, we will be able to reduce petroleum imports in the US by $248B/year, and reduce $CO_2$ emissions by 642 Mtons/year.
- Biofuels are supported by a strong agro-sector, and now by oil.
- EPACT 2005 and ESIA 2007 incentives for US biofuel and mandates for use of ethanol ensure that the industry will prosper and become cost competitive.
- **DOES THAT MEAN EVERYTHING WILL BE OK?**

# Thermal Energy Conversion




- Thermal energy conversion has a 70-85% energy loss in automotive applications. This waste heat is over and above the heat coming in from the sun.
- We are consuming fossil fuel at >1000X the rate at which it was made by nature, and emitting most of it as waste heat – not sustainable. Maybe biofuels are the answer!!
- When the fuel is simply extracted from the ground from a limitless supply, one can accept 70-85% lost energy, provided the economics works out.
- If the fuel has to be made, there is a 300-500% penalty and cost, assuming no energy consumption in the process of making the fuel itself.
- Existing biofuel processes are very inefficient – suggests the need for very low cost in the process of manufacturing and distributing biofuels.
- Needs to be examined in a framework of sustainability.

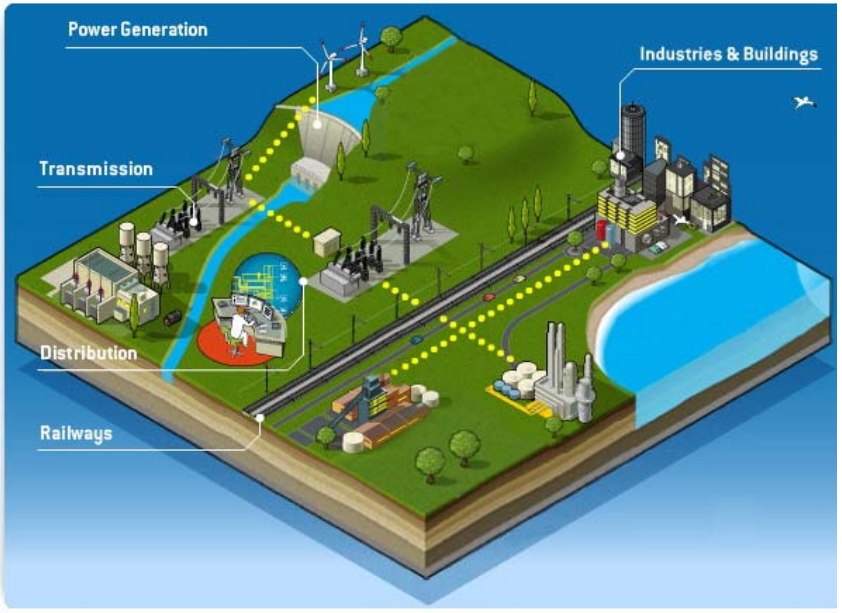
# Defining a Sustainable Energy Ecosystem



# Transportation Energy Scenarios

- Resource Interdependency Model
  - To test the sustainability of various scenarios
  - Multi-flux model to capture interdependencies and minimize unintended consequences
  - Fluxes included – landmass, fresh water, biomass, carbon and energy
- Four Scenarios:
  - BAU: Business As Usual – Its OIL!
  - EFW: Electrically Fueled World – transit needs met with conventional electricity sources
  - BFW: biofueled World – transit needs met with biofuels, leverages fuel infrastructure
  - IFW: Inorganically Fueled World (Solar PV, Wind etc) – transit needs from renewable sources such as solar PV, leverages electricity infrastructure


**Biofueled World**




**Inorganically Fueled World**

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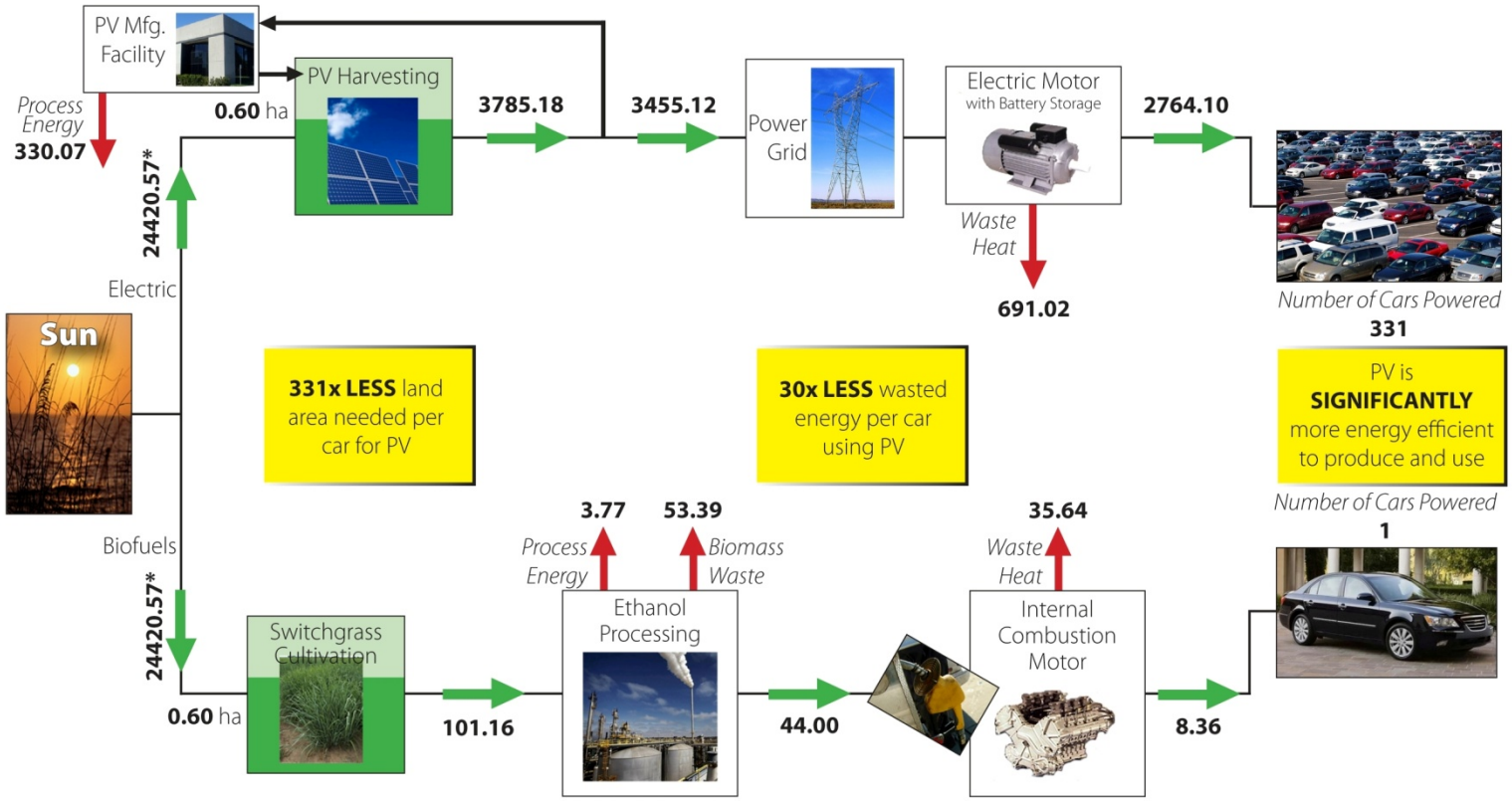
# Electricity Powered Cars (EFW) - US

- Carlos Ghosn (Economist) stated that the future belongs to electric cars

- Electricity powered cars require on-board energy storage - Batteries, Hydrogen or Compressed Air.
- $CO_2$ emissions reduced to 469 Mtons-C/year (from current 642 Mtons-C/year).
- Builds on proven HEV technology.
- Interim use of PHEVs until battery and fast-charging infrastructure are improved.
- Integration with Smart Grid initiatives to reduce new generation build-out (V2G).
- Gaps: batteries, charging infrastructure, policy, green electrons, validation processes, (already in place – drives technologies integrated with cars, batteries – less than 2x improvement needed)
- Challenges – Will Lithium be the new oil. Needs >300 GW new generation.
- Business models show that the PHEV/EV is sustainable within the right policy environment.

# Sustainable Energy Supply Chain for Driving 30 Miles/Day

PV-powered electric motor vs. bioethanol-fueled internal combustion motor




- Green arrows are energy flows, red arrows are waste energy. All units in kWh/day.
- Bioethanol and electricity transportation losses have been omitted.
- Sustainable energy supply chains require no fossil fuels and produce no net carbon emissions.

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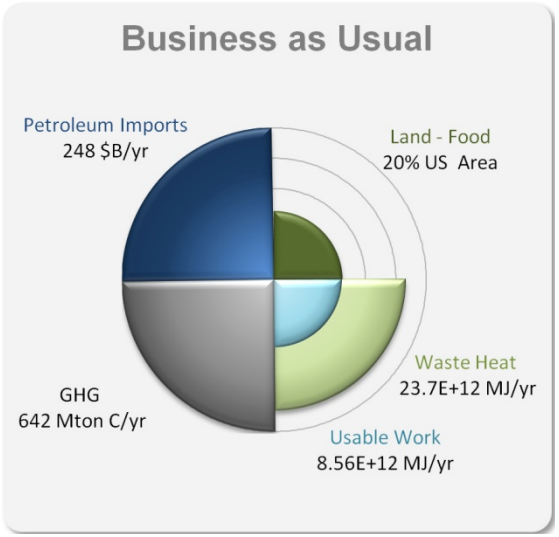
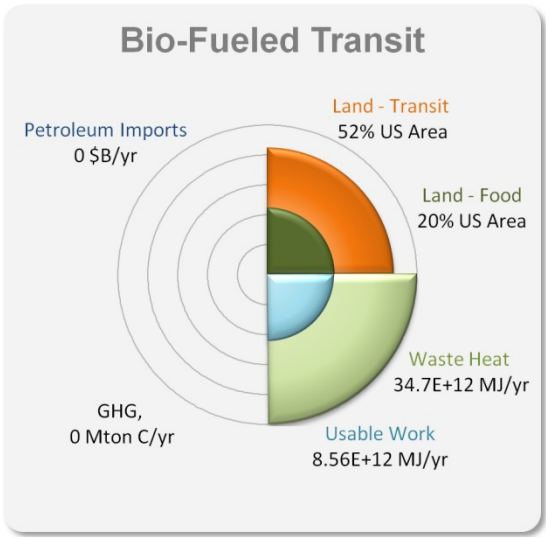
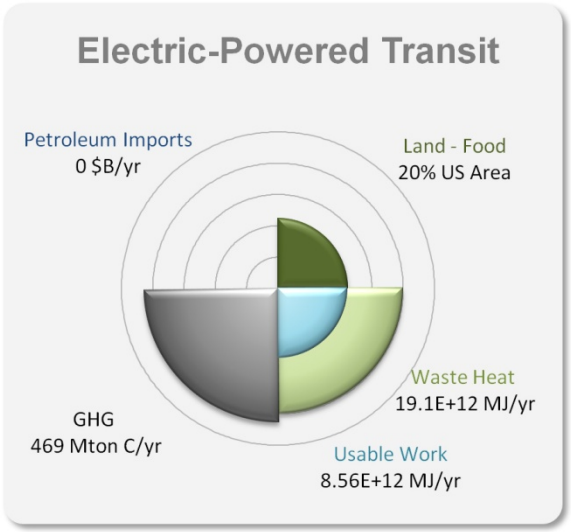
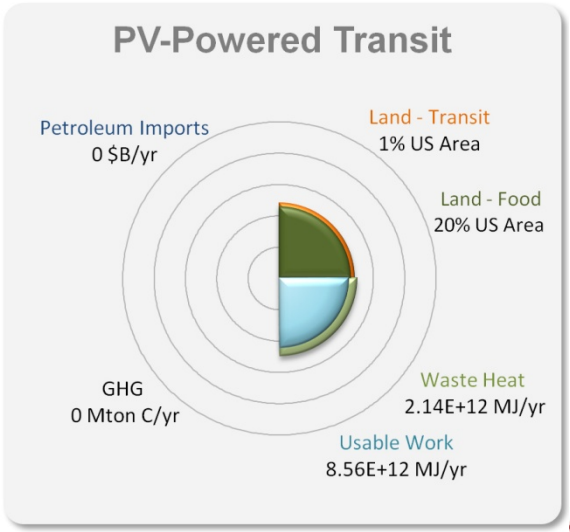
# Sustainability Comparison of Four Scenarios – Transit

| | Fossil Fuels | Sustainable Energy |
|---|---|---|
| **ICE Transit** |  |  |
| **Electric Transit** |  |  |









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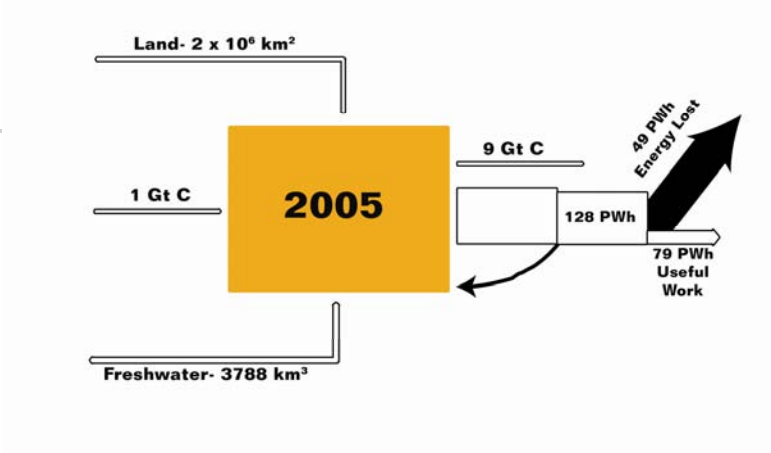
# Global: Sustainable Energy Scenario – 2030 Assumptions

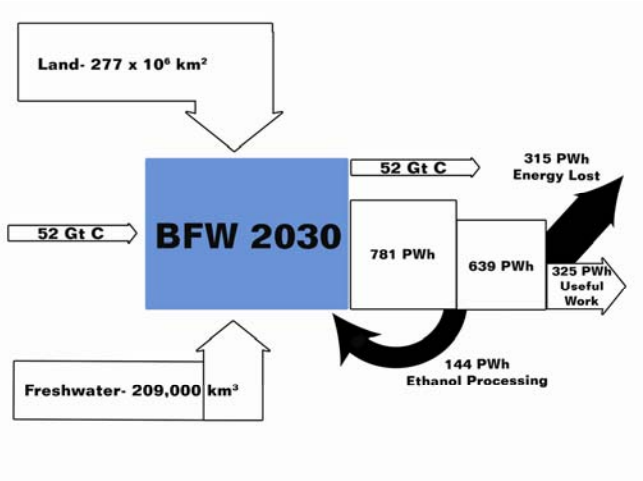
- 9.1 Billion people on the planet
- Average global standard of living equivalent to 2006 US levels
- 800 kg per capita grain (US-2006 v/s 200 kg for India)
- 343 $m^3$ of water for non-energy, non-irrigation use (US-2006 level)
- Average global utility equal to US 2006 average (82 MWh per-capita/year v/s 4.3 MWh/yr in 2006 for India).
- All global land and water may be utilized to support human life.
- Lossless transportation of electrical energy and water through the world.
- Bioenergy delivered from switchgrass ethanol (13.5t/ha, ROE 4.43) – requires less land, water and energy than corn ethanol.
- Electrical energy from PV (4 kWh/$m^2$/day insolation at 15.5% efficiency).
- Two-crop food model (winter wheat and corn).

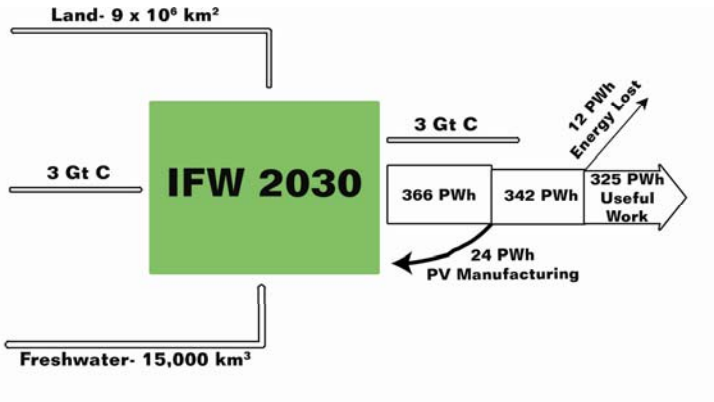
This is an optimistic assumption. If sustainability will not work in this scenario, it will definitely fail under more realistic conditions.

# Sustainable Energy Scenario Results

- Business as Usual – 8 GT-C/year net emissions.
- Biofueled World requires 31X land and 14X water of the Inorganically Fueled World scenario
- BFW requires **187%** the global total land area available – impossible!
- BFW requires **177%** the global terrestrial rainfall – impossible!
- By way of comparison, IFW requires one-twentieth (5%) of dry land and one-eighth (12%) of global rainfall to meet all human requirements of food, water and energy.
- IFW can scale with human population and prosperity without increasing carbon emissions or putting unreasonable strain on land or water use.
- Suggests that BFW may need extraordinary technology gains to become the primary energy source.
- Cost savings of BFW over IFW have to be really dramatic to adopt it as a preferred solution.

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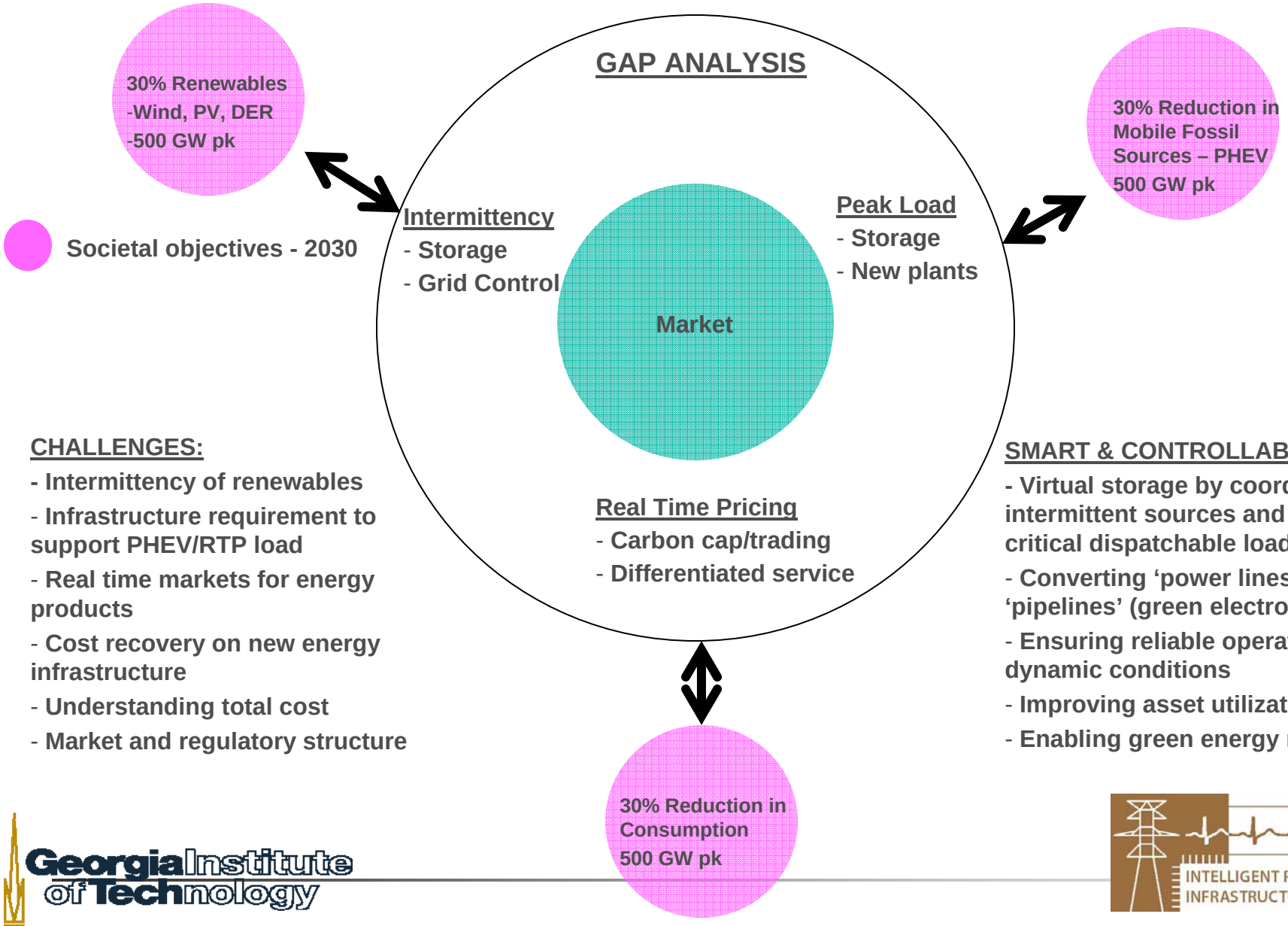
# Infrastructure Gaps – Inorganically Fueled World




**CHALLENGES:**

- Intermittency of renewables
- Infrastructure requirement to support PHEV/RTP load
- Real time markets for energy products
- Cost recovery on new energy infrastructure
- Understanding total cost
- Market and regulatory structure

**SMART & CONTROLLABLE GRID:**

- Virtual storage by coordination of intermittent sources and non-critical dispatchable loads
- Converting 'power lines' into 'pipelines' (green electron delivery)
- Ensuring reliable operation under dynamic conditions
- Improving asset utilization
- Enabling green energy markets

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INTELLIGENT POWER INFRASTRUCTURE CONSORTIUM

## So What Does This Mean?

- Biofuels may have severe problems in terms of scalability – likely to remain a niche play. Subsidies can create momentum along an unsustainable path, making subsequent course corrections difficult.
- Electricity powered cars show great promise. Underlying automotive technology well understood by auto manufacturers. Significant momentum shift seen for introduction of EVs and PHEVs.
- In the long-term, electric cars powered from inorganic sources (not biofuel) promise sustainable operation with minimal resource use.
- For high EV penetration, significant gaps remain – batteries, fast-charging and lack of a smart grid infrastructure.
- IFW scenario is scalable, sustainable and can serve as primary energy source, even allowing for dramatic increase in global GDP and prosperity. Resource use does not create strong interdependencies or upset the biological web.
- Biomass and water should be maintained for human sustenance. This would maximize biodiversity, reduce greenhouse emissions to stable and sustainable levels, while providing abundant energy for global growth.

- **The future looks increasingly like an 'Electron Economy', where electricity is the primary energy delivery mechanism.**



## Sustainable Energy – Some Thoughts

- This presentation explores sustainable energy from a multi-flux perspective and shows that biofuels, may have limits on scalability, and may significantly impact biodiversity, and food/water availability.
- An inorganically fueled world, on the other hand, shows robust scaling to meet global growth for the foreseeable future, with minimal impact on biodiversity.
- A detailed multi-flux model is used to construct various scenarios. A key constraint is allowing all countries to develop to their full potential without in any way getting constrained by a lack of energy, food or water resources.
- Automobiles transitioning to electricity, and finally inorganic energy, powered operation, offer some of the best opportunities for moving to sustainability.
- Public policy should not incentivize solutions that are not sustainable, as it causes perverse and unintended consequences. Rather, public policy should set long-term direction through regulatory policy as well as financial incentives.
- Emerging economies such as China and India should invest in a sustainable future today and become leaders in this critical technology area.
- The final question is not whether we can afford to implement a sustainable energy infrastructure, but whether we can afford not to!